Comment on K. Michaelian and A. Simeonov (2015) "Fundamental molecules of life are pigments which arose and co-evolved as a response to the thermodynamic imperative of dissipating the prevailing solar spectrum".

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Abstract. This is a comment on: "Fundamental molecules of life are pigments which arose and co-evolved as a response to the thermodynamic imperative of dissipating the prevailing solar spectrum" by K. Michaelian and A. Simeonov,

10 Biogeosciences, 12, 4913–4937, 2015. Michaelian and Simeonov formulate the leading thought in their article "The driving force behind the origin and evolution of life has been the thermodynamic imperative of increasing the entropy production of the biosphere through increasing the global solar photon dissipation rate". I doubt that the reasoning that follows regarding the role of "pigments" (in which they include all substances able to absorb solar radiation) is correct.

1 Introduction: Do living systems reduce the albedo of Earth?

15 Already in the first sentence of their abstract Michaelian and Simeonov formulate the leading thought in their article "The driving force behind the origin and evolution of life has been the thermodynamic imperative of increasing the entropy production of the biosphere through increasing the global solar photon dissipation rate". We doubt that the reasoning that follows regarding the role of "pigments" (in which they include all substances able to absorb solar radiation) is correct.

20 As long as light travels freely in space, there is no change in the entropy associated with it. If it is scattered, entropy is increased. A surface reflecting light in a diffuse way (i.e., non-specularly), will increase entropy by scattering, not by changing the photon number. An absorbing surface will eventually cause the light to be converted to diffuse radiation of an increased number of less energetic photons, and thus increase entropy more than a reflecting surface (see, e.g., Delgado-Bonal 2017). Thus, it appears that if Michaelian and Simeonov are correct, one would expect organisms, in particular

25 phototrophic organisms, or the biosphere) to be less reflecting and more absorbing than dead matter. They explicitly state: "Living systems reduce the albedo of Earth". Is this correct?

2 Albedo of the Moon, a world without life

Early phototrophic organisms are thought to have evolved in water, and we shall deal with this later below, but start with the
30 situation on land. Let us compare the optical properties of ground with and without vegetation, and those of of the Moon
with those of the terrestrial biosphere (by "terrestrial" we here mean not only "on planet Earth", but specifically "the part on
land").

When you look at the Moon you will see brighter areas ("highlands") and darker areas ("mare"). Figure 1 (courtesy E. Foote
35 Smith) shows what the materials in these two kinds of lunar surface look like close-up. As expected, the mare soil is darker
than the highland soil, but the highland soil probably does not look as white as expected. Remember that when we look at the
Moon at night it is against a background of a dark sky, and our eyes are dark-adapted. We are fooled by the great contrast.
And the surface of the moon is not more reflecting than plant leaves (Figure 2).

40 **3 Vegetation compared to bare ground**

Vegetation does not always look darker than ground without vegetation (Figure 3). What is important in the context of what
we are dealing with here is of course not what things look like. We must extend our interest into the infrared, a spectral
region to which much of the solar radiation belongs (the ultraviolet is of less interest in this context). And the quantity we
should consider as far as data are available is the hemispherical reflectance, not reflectance in a single direction.
45 Unfortunately, in most cases values of hemispherical reflectance are not available. Directional reflectance spectra (Figure 4,
Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/)) seem to indicate that vegetated areas
may reflect more light throughout the daylight spectrum (Figure 5, CC BY-SA 3.0) than bare ground.

4 The temporal aspect

50 We can also put a temporal aspect on this. If sunlight is absorbed by dead matter, it is usually converted to heat and
reradiated as heat radiation of ambient temperature within a short time. If it is absorbed by a photosynthetic system, much of
the energy is retained for a long time, before eventually it is radiated as heat radiation, sometimes after having been
processed through several steps in the food chain. Thus, the living system delays entropy increase. Some trees that had
collected solar energy sank into swamps more than two hundred fifty million years ago, and their reduced carbon was
55 preserved until the present era, when mankind started to burn coal and thereby generate entropy. Thus, entropy production
was delayed, i.e. the rate of production decreased, thanks to the chlorophyll and the photosynthesis of ancient trees that have
been preserved as coal. The production and usage of oil is a similar phenomenon. We cannot back from our responsibility for
our planet by claiming that we must burn all the coal and oil due to a "thermodynamic imperative".

60 **5 The aquatic environment**

Much of the Earth surface is covered by water, and much of life's evolution has taken place in water. Thus we must also
consider the reflectance of water bodies, and how their reflectance is affected by life.

Organisms at sea do not decrease the reflectance of the ocean (Figure 6).

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Almost half the land area in Figure 6 looks quite dark. This area is covered by coniferous forest, mainly Scots pine (*Pinus sylvestris*) with some spruce (*Picea abies*). We must not be misled by the dark appearance; the reflectance is higher from 700 to 1300 nm (a substantial part of the solar spectrum, c.f. Fig. 5) than in the visible spectral region (Rautalainen et al. 2018). There are some small quite bright areas on the land surface. These bright areas consist of bare carbonate rock, also a result of

70 (past) life. Another circumstance, not visible in Figure 6, is that forests have a tendency to increase cloudiness, and thereby cause increased reflectance by the atmosphere (e.g., Teuling et al. 2017), and thereby counteract entropy increase.

I do not have available spectral curves from the sea shown in Figure 6, but turn to analogous situations described by Qi et al. (2020). They have published numerous reflection difference spectra for various lakes and ocean surfaces where algae are

75 abundant, i.e. spectra that show the difference in reflectivity for water with and without algae. A sample is reproduced in Fig. 7.

The presence of algae increases the reflectivity of oceans and lakes, i.e. counteracts the "degradation" of sunlight to diffuse radiation of longer wavelength, and thus the production of radiation entropy.

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As far as we know there is no life on Mars; nevertheless the reflectivity (albedo) is very low even in brighter areas like Syrtis Major, although during dust storms, the albedo increases (Vincendon et al. 2015). The low reflectivity holds particularly for short wavelength (422 nm), but even red rocks reflect less than 10% of incident 733 nm and 1009 nm radiation over most angles (Johnson et al. 2021).

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6 Conclusion

Michaelian & Simeneov (2015) conclude that they have presented evidence that "supports the thermodynamic dissipation theory of the origin of life (Michaelian, 2009, 2011), which states that life arose and proliferated to carry out the thermodynamic function of dissipating the entropically most important part of the solar spectrum (the shortest wavelength

90 photons) prevailing at Earth's surface and that this irreversible process began to evolve and couple with other irreversible abiotic processes, such as the water cycle, to become more efficient, to cover ever more completely the electromagnetic spectrum, and to cover ever more of Earth's surface."

I cannot agree that they have presented evidence for this conclusion. The biosphere has certainly evolved and is maintained

95 thanks to a production of entropy associated with the conversion of solar radiation to Earth radiation. For details of this

entropy production, I refer to Wu and Liu (2010). They compared and discussed various ways of computing entropy fluxes in the Earth system.

7 There are no competing interests

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8 Acknowledgements

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140   **Figure 1. Close up images lunar mare soil (collected by the Apollo 11 mission) and lunar highland soil (Apollo 16 mission). The width of each closeup sample image is 1 cm. From Foote Smith (2019) with permission by the author.**
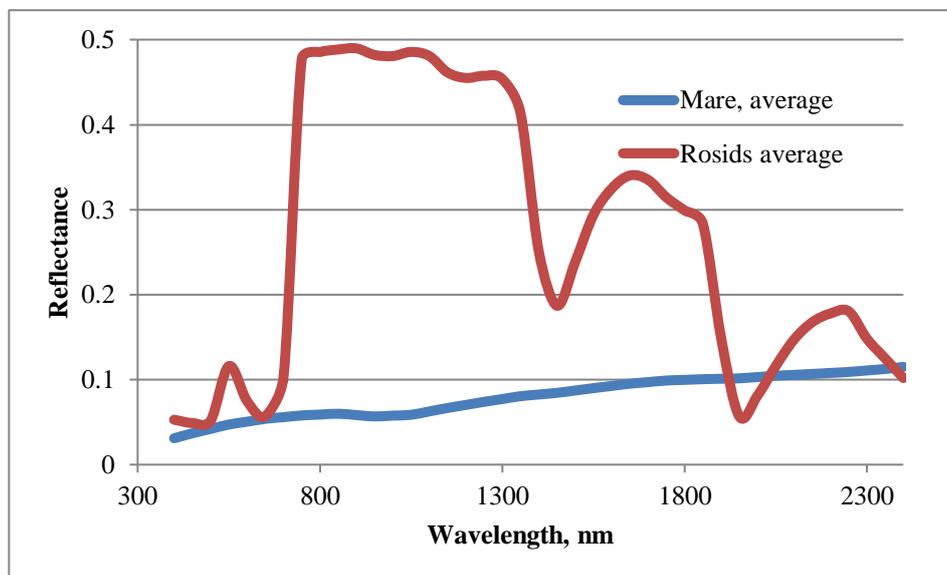
Figure 2. Average reflectance spectra of four different lunar mare sites (sites 5, 6, 7, 8), redrawn from Wu and Hapke (2018); also reproduced in Wu et al. (2018), and average reflectance of leaves of about 300 plant species of the rosid clade redrawn from Meireles et al.(2020). Over most of the spectral range, the reflectance is higher and the absorbance lower for the plant leaves.

Figure 3. Not everywhere does the vegetation look darker than the unvegetated ground, Punaluu Beach, Hawaii. Photo by Diego Delso. Creative Commons Attribution License (https://creativecommons.org/licenses/by-sa/4.0/).
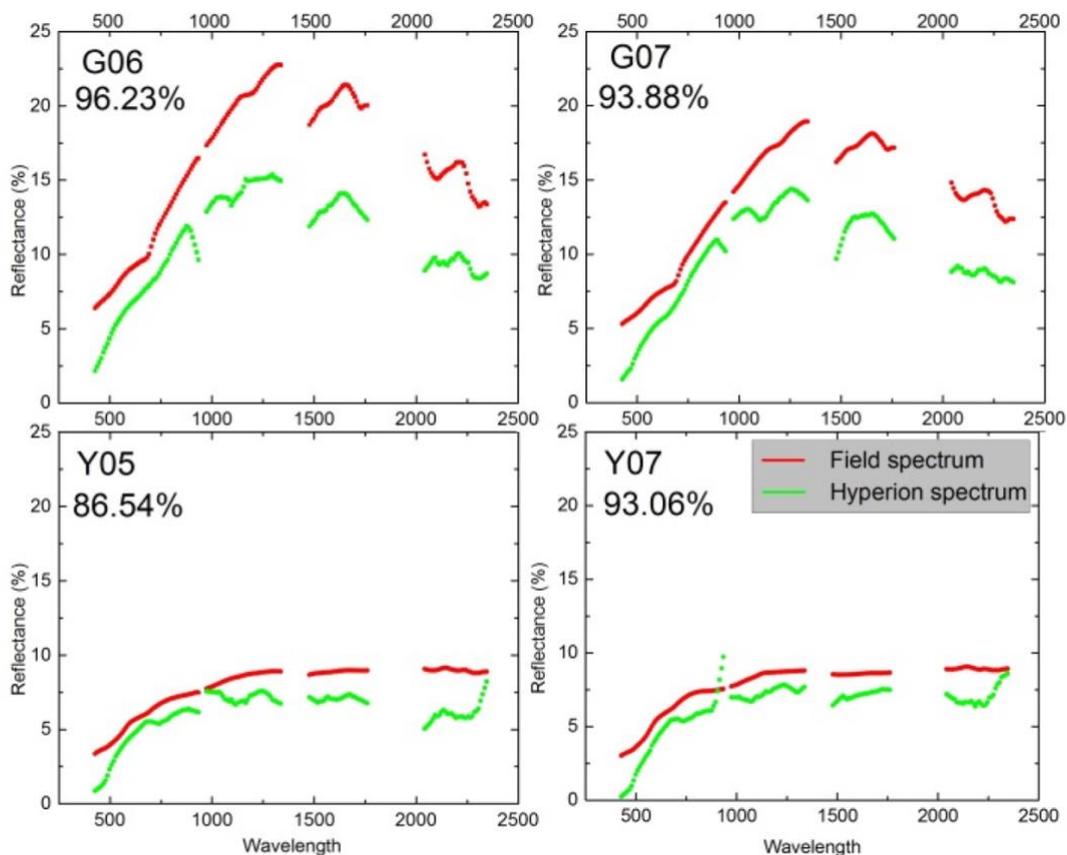
Figure 4. Reflectance spectra from the volcano Teide on Tenerife, one of the Canary Islands. The spectra were recorded on the ground (red) or remotely from satellite (green). The percent values indicate the agreement between the red and green curves. Top left (G06) is from a site with heavy lichen cover but no plants, top right (G07) heavy lichen cover and some plants. Bottom panels show spectra av bare lava (no vegetation). From Li et al. (2015). Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/).

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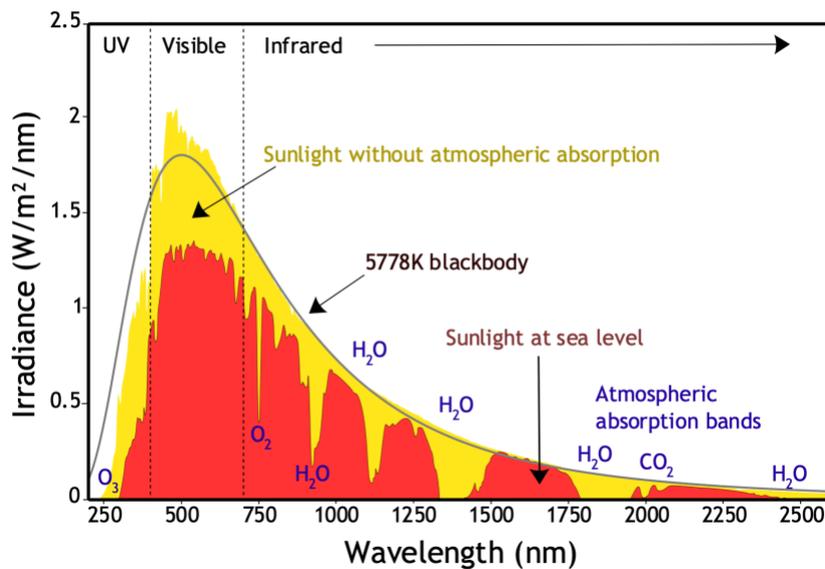
Figure 5. Spectrum of sunlight outside the atmosphere and at ground level. Most of the radiation falls below 1000 nm, where lunar mare absorbs more than 90%. From Nick84 - File:Solar_spectrum_ita.svg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=24648395.
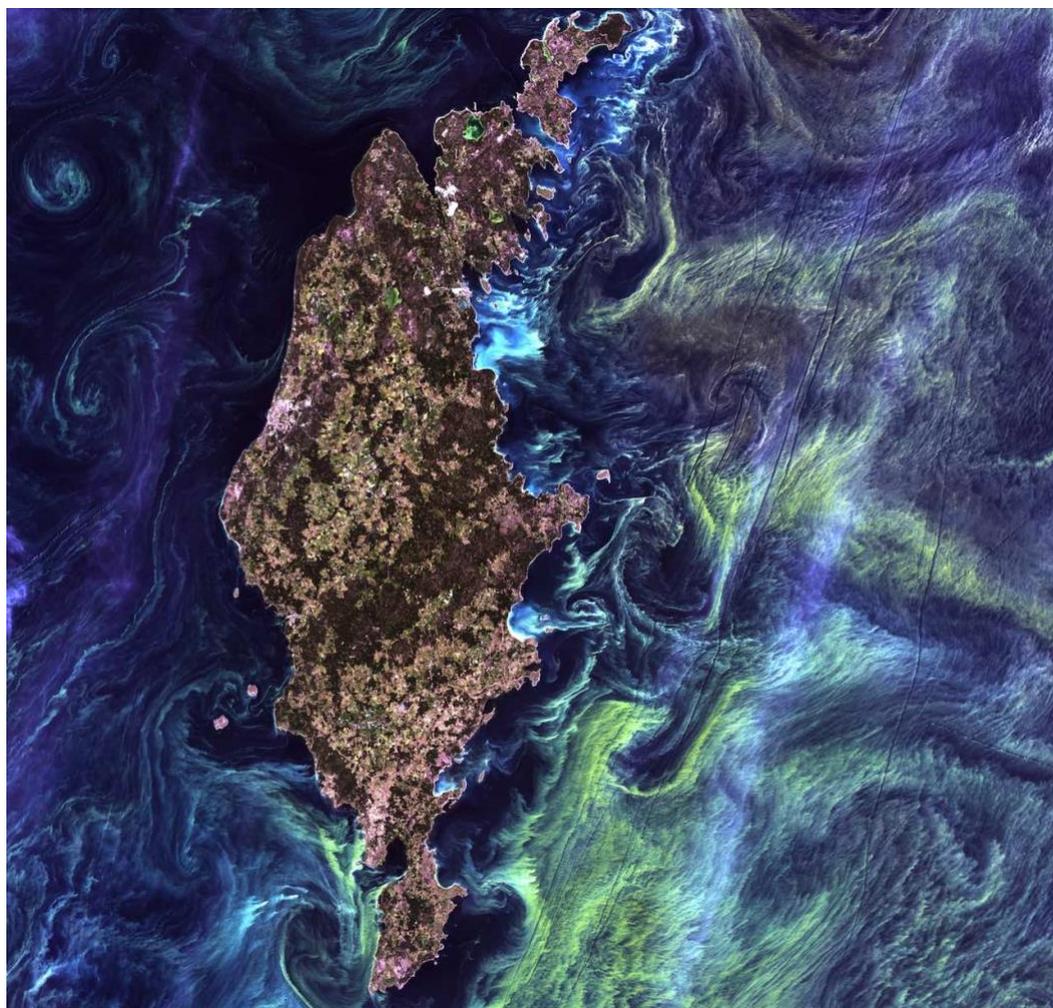
Figure 6. My home island Gotland surrounded by the Baltic Sea. On the Eastern side there is an algal bloom, which appears to reflect more light than the more nutrient-poor water on the Western side of the island. Image and caption courtesy of NASA Goddard Photo and Video photostream. Credit: USGS/NASA/Landsat 7.
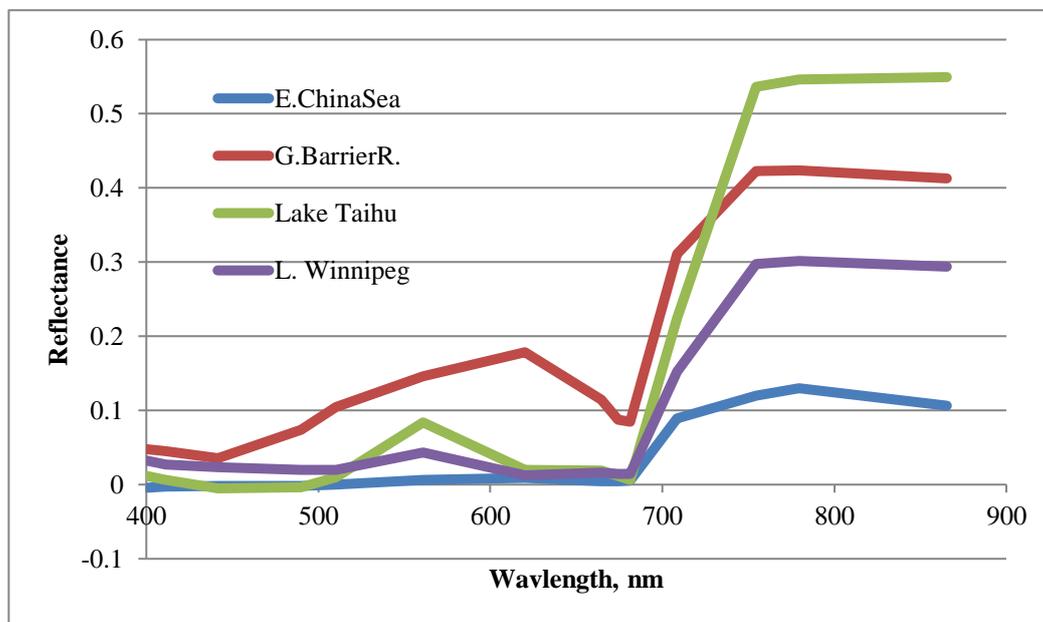
Figure 7. A sample of sea and lake reflectance difference spectra redrawn from Qi et al. (2020). The diagram shows reflectance of waters with algae minus adjacent water without algae. These differences are almost always positive, in some cases with the exception for small negative excursions at short wavelengths.

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